SFERIC WAVEFORM IDENTIFICATION OF DESTRUCTIVE WINDSTORMS AND TORNADOES

By

JAMES C. HILL

Bachelor of Science

Oklahoma Agricultural and Mechanical College

Stillwater, Oklahoma

1950

Submitted to the Faculty of the Graduate School of

the Oklahoma Agricultural and Mechanical College

in Partial Fulfillment of the Requirements

for the Degree of

MASTER OF SCIENCE

1951

SFERIC WAVEFORM IDENTIFICATION

OF DESTRUCTIVE WINDSTORMS AND TORNADOES

JAMES C. HILL

MASTER OF SCIENCE

1951

THESIS AND ABSTRACT APPROVED:

Herbert L. Jones
Thesis Adviser

A. Naeter
Faculty Representative

D. C. McIntosh
Dean of the Graduate School

PREFACE

The destructivity of tornadoes and other high energy storms is well known in the Southwest. Research on electronic detection and identification of these destructive windstorms, under the direction of H. L. Jones, has been in progress at Oklahoma Institute of Technology for the past three years.

Purposes of this study are to describe waveforms characteristic of various atmospheric disturbances and to pave the way for future research by presenting detailed operational data on equipment herein employed.

ACKNOWLEDGMENT

The author wishes to express his appreciation for assistance to the Oklahoma Institute of Technology staff in general. He is particularly indebted to Dr. Herbert L. Jones, under whose supervision this study was conducted.

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTINUED)

LIST OF TABLES

LIST OF ILLUSTRATIONS

CHAPTER I

INTRODUCTION

Previous research at Oklahoma Institute of Technology has conclusively demonstrated that atmospheric disturbances possess characteristic waveforms. This study was designed to record and to depict graphically such waveforms, from their initial formation to their conclusion, typical of atmospheric disturbances which could result in destructive windstorms.

The nature of atmospheric disturbances is such that the recording of them necessitates the use of electronic equipment. The basic design of the electronic equipment used at Oklahoma Institute of Technology was completed in 1948 by Jeske[1] after a study of sferic[2] theory to determine the demands that would be placed upon the recording gear.

Detection of Sferics

The detection device of the equipment consists of a short whip antenna which has at its base a cathode follower to couple the antenna to a video amplifier which has a response characteristic of 20 cycles per second to 200 kilocycles per second. The impedance matching cathode follower was necessary because of the wide range of frequencies and because of lower end response attenuation and phase shift which are inherent in any amplifier.

---

1 Jeske, Harold O., Electronic Apparatus for the Study of Sferic Waveforms, Master of Science Thesis, Oklahoma Agricultural and Mechanical College, 1949.

2 The term "sferic" will herein after refer to atmospheric electromagnetic waves originated by weather phenomena.

Recording of Sferics

The recording device is a modified shutterless 35 mm. motion picture camera which is actuated by a rotary solenoid. The solenoid advances the camera film one frame (3/4 in.) per detected sferic. The camera is attached to a light-tight box in which is a model 250 DuMont oscilloscope, a time-date clock, a strobotron tube to illuminate the clock, and a direction finder cathode ray tube. All these components are gated from a trigger circuit which is initiated by a detected sferic.

Direction Finding Device

The direction finding device, developed by Thomason,[3] consists of two bi-directional loop antennae placed at right angles to each other. The bi-directional characteristic is necessary because of the relatively short duration, 4 to 8 milliseconds, of sferic disturbances. The detected signals in each antenna are fed to amplifiers which have identical amplification and phase shift characteristics. The north-south detection antenna has its output fed to the vertical deflection plates of a cathode ray tube, and the east-west antenna has its output placed on the input of the horizontal deflection plates of the cathode ray tube. The sferic signal produced on the cathode ray tube thus has the greatest amplitude in the direction of the received sferic.

The 180° ambiguity of a single loop antenna has been relieved by correlating received sferics with the fronts shown on

---

[3] Thomason, Thomas H., The Development of a Sferic Direction Finder, Master of Science Thesis, Oklahoma Agricultural and Mechanical College, 1949.

daily weather maps.

Equipment Operation

The sferic detection and recording equipment has been in operation for approximately one year with encouraging results. However, field condition testing and operation indicated a need for a few minor refinements in the trigger circuit and recording apparatus, refinements which were subsequently made and which are explained in a later chapter. Also explained in a later chapter are several operational adjustments which must be made during each period of sferic disturbance.

The purposes of this study are to complete circuit refinement, to present detailed explanation of equipment operation, and to show pictorially the various sferic characteristic waveforms. The waveform pictures should facilitate future related research by identifying sferic waveforms characteristic of destructive windstorms and tornadoes.

CHAPTER II

SFERIC GENERATION THEORY

Origin of Sferics

Sferics are electromagnetic disturbances which emanate from centers of fronts of meteorologic or ionospheric change. These fronts are commonly called squall lines or pressure areas. Previous study of weather conditions has led many scientists to the belief that all sferics are generated in storms. Some confusion exists as to the exact origin of sferics because of a lack of synoptic coordination.

Smith-Rose[1] pointed out that all sferics of importance originate in mountainous areas. With normal convection current, heated air rises to the upper atmosphere with subsequent cooling which causes polarity change or separation of charges existing in the hot air mass. This change of polarity or charge separation causes a discharge which results in sferic generation.

Austin[2] pointed out that not all sferics have their origin in thunderstorms since he noted that in a region of thunderstorm activity, sferics are not necessarily created by lightning discharges.

---

[1] R. L. Smith-Rose, "Atmospherics", World Power, Vol. 3 (1925), pp. 20-25.

[2] L. W. Austin, "The Direction of Atmospherics in Wireless Telegraphy", Journal of the Franklin Institute, Vol. 121 (1921), pp. 619-720; "Radio Atmospheric Disturbances", Washington Journal of Academic Science, Vol. 16 (1926), pp. 41-46.

Austin[3] also posed the hypothesis that interference with communication is caused by sferic generation in the upper atmosphere and compared it to radio signal propagation from an airplane. From an airborne transmitter the electromagnetic wave front spreads out in a spherical form. When the wave strikes the earth, the electromagnetic lines of force will ground and travel over the surface as though transmitted from a point source below the center of the disturbance.

Dean[4] reported an attempt to correlate quantity and direction of sferics with existing weather phenomena. He pointed out that the directions from which atmospherics come coincide with existing thunderstorm bearings, and that atmospherics are due to lightning discharges, the sferic frequency being that of the rate of lightning discharge.

Dean further reported that low pressure areas seem to produce more atmospherics, particularly when moving rapidly, and that lows produce many more sferics when moving over land than when passing out to sea.

In his conclusions Dean[5] pointed out the utility of a cathode ray range finder for sferics and the added advantages of

---

[3] L. W. Austin, "The Relation Between Atmospheric Disturbances and Wave Length in Radio Reception", _Proceedings of the Institute of Radio Engineers_, Vol. 9 (Feburary, 1921), pp. 28-35.

[4] S. W. Dean, "Correlation of Directional Observations of Atmospherics with Weather Phenomena", _Proceedings of the Institute of Radio Engineers_, Vol. 17 (July, 1929), p. 1186.

[5] Ibid., p. 1191.

cathode ray triangulation ranging for sferic directional detection. The present study has been conducted with just such apparatus except that only one observation station was employed.

The origin of a particular sferic was investigated by Hucke.[6] This sferic has the name "precipitation static", since it is experienced when aircraft fly through rain, snow, hail, ice crystals, and dust clouds. Hucke found that an airplane flying through a front will break up water particles with its propeller and wing and cause a corona or sferic generating discharge. Also, the wings of the aircraft collect charges when going through a cloud of one polarity and lose that charge when passing through a cloud of opposite polarity, with resultant sferic generation.

Hucke also attacked the problem of static interference meteorologically. He advanced the theory that the air surround ing the earth's surface is not normally in equilibrium due to the fact that the solar energy tends to heat certain portions more than others, and as a result these heated portions will rise. As the hot air rises, the electrostatic field surrounding the earth becomes distorted. The rising air conveys moisture to the colder regions aloft and this moisture condenses to fog and forms clouds. If the rising air moves rapidly, the water droplets are churned about and the cloud becomes unstable electrostatically, with resultant lightning discharges and sferic generation.

---

[6] H. M. Hucke, "Precipitation-Static Interference on Aircraft and at Ground Stations", Proceedings of the Institute of Radio Engineers, Vol. 27 (May, 1939), pp. 301-309.

Sferic origin, for this study, is assumed to be in weather fronts or squall lines. It is the writer's opinion that Austin's assumption has been validated because of the observed correlation between lightning discharges and the simultaneous recording of sferic waveforms by the equipment used at Oklahoma Institute of Technology for sferic study. During a thunderstorm or incipient tornado period the rate of sferic occurrence approaches 2 per second, the sferic being of large amplitude and high intensity.

Sferic Wave Nature

The wave nature of sferics has many classifications. Oscilloscopic studies at Oklahoma Institute of Technology have found sferic waveforms to be oscillatory with varying degrees of amplitude, intensity, and periodicity. Observed lightning discharges have presented waveforms which appear to be oscillatory in nature, yet which do not follow a damped oscillatory path. Instead, there have been waveforms presented on the oscilloscope which could follow a damped sine wave path and yet produce another high amplitude damped oscillatory wave at mid axis. Schonland[7] and his co-workers have advanced the explanatory assumption that most sferics consist of a ground pulse followed by a series of sky pulses caused by successive reflections between the earth and the ionosphere. The primary pulse is usually a single oscillation with a period of 50 to 400 microseconds. The time separation between peaks is proportional to the distance

---

[7] B. F. J. Schonland, D. J. Malan, and H. Collens, "Progressive Lightning II", Proceedings of the Royal Society, Vol. 153 (1935), pp. 595-625.

traveled and the height of the discharge layer above the ground.

It is hoped that amplitude, duration, and intensity of sferics will serve as guides to the identification of sferic waveforms characteristic of tornadoes and destructive windstorms. Schafer and Goodall[8] learned from their observations that the duration of any particular lightning stroke is of the order of 10 miliseconds. They also found that lightning flashes from a distance of 15 miles produce peak field strengths of 1 millivolt per meter, and that a storm 5 miles distant produces an approximate intensity of 3 millivolts.

Sashoff and Weil[9] have reported the following characteristics of sferics based upon their observations of six tropical storms:

1. There is a random distribution of static crashes during the early afternoon and evening runs which suggests that most of the disturbances during this period are of local origin;

2. A considerable amount of static arrives from the direction in which a storm is known to exist;

3. Although the intensity of static from such a direction varies, such static seems to persist on successive runs;

4. The direction of the persisting static changes in close relationship to the shifting of position by the storm;

---

[8] J. P. Schafer and W. M. Goodall, "Peak Field Strength of Atmospherics Due to Local Thunderstorms at 150 Megacycles", Proceedings of the Institute of Radio Engineers, Vol. 27 (March, 1939), pp. 202-204.

[9] S. P. Sashoff and J. Weil, "Static Emanating from Six Tropical Storms and Its Use in Locating the Position of the Disturbance", Proceedings of the Institute of Radio Engineers, Vol. 27 (November, 1939), p. 698.

5. Static from directions like the above seems to disappear with the disappearance of the storm;

6. Many of the crashes in a given direction occur in groups of two or threes. This is attributed to thunder-cloud discharges, which may be expected to have a tendency to occur in groups;

7. The intervals between individual crashes occurring in a group were found to be of the order of 5/100 second;

8. The best records were obtained between the hours of midnight and 12:00 noon.

Intensity and frequency distribution characteristics of sferics were investigated by Potter.[10] His observations were primarily in the 2 to 20 mcps. range, but his report included the 15 to 60 kcps. range. The significant finding of his report, so far as the present study is concerned, is that there are maxima throughout a day of sferic disturbances of high intensity in the 10 to 30 kcps. range. Equally significant for present purposes is his finding that the diurnal variation of sferics has its maximum intensity in the range of 50 kcps. and below.

The sferic recording equipment at Oklahoma Institute of Technology can be operated in the 50 cps. to 150 kcps. range, with normal operating frequency in the 5 kcps. to 50 kcps. range. It is significant that the operating frequency range of the equipment used in the present study is the range found by Potter to be characterized by the greatest number of sferics and the

---

10 R. K. Potter, "An Estimate of Frequency Distribution of Atmospheric Noise", Proceedings of the Institute of Radio Engineers, Vol. 20 (September, 1932), pp. 1512-1518.

largest amplitude.

Relation of Sferic Disturbances to Tornadoes

Previous research at Oklahoma Institute of Technology has indicated a close correlation between sferic disturbances and tornadoes. It has been demonstrated that there are distinctive waveforms which are characteristic of particular types of sferics. However it is hoped that subsequent research will delineate a waveform which is characteristic of sferics generated by a tornado only. A key to such a potential characteristic waveform may lie in the six pre-tornado conditions enumerated by Fawbush, Miller, and Starret.[11]

1. A layer of moist air near the earth's surface must be surmounted by a deep layer of dry air;

2. The hroizontal moisture distribution within the moist layer must exhibit a distinct maximum along a relatively narrow band;

3. The horizontal distribution of winds aloft must exhibit a maximum of speed along a relatively narrow band at some level between 10,000 and 20,000 feet, with the maximum speed exceeding 35 knots;

4. The vertical projection of the axis of wind maximum must intersect the axis of the moisture ridge;

5. The temperature distribution of the air column as a whole must be such as to indicate conditional instability;

6. The moist layer must be subjected to appreciable lifting.

Future research students at Oklahoma Institute of Technology might set for themselves the following objectives which, in the light of present knowledge, appear attainable:

---

[11] E. J. Fawbush, R. C. Miller, L. G. Starrett, "An Empirical Method of Forecasting Tornado Development", Bulletin of the American Meteorology Society, January, 1951, pp. 1-9.

1. To predict tornadoes through the use of daily weather maps which indicate the presence or absence of the conditions outlined by Fawbush, Miller, and Starett;

2. To detect and identify tornadoes by their sferic characteristics, using the detection equipment at Oklahoma Institute of Technology;

3. To track tornadoes by means of radar;[12]

4. To develop a network of sferic detection, identification, and tracking stations encompassing the Southwest; and

5. To devise an adequate warning system.

---

12 The installation at Oklahoma Institute of Technology of a radar complex is planned for the near future.

CHAPTER III

OPERATION OF EQUIPMENT

Sferic detection equipment is necessarily custom built; hence, initial design and operation of such equipment require practical orientation. The primary purpose of this study is to speed future research by presenting detailed operational procedures of component parts of the apparatus and by indicating maintenance requirements.

Antenna and Cathode Follower Circuit

The whip antenna as such requires no maintenance. However, the cathode follower circuit located in a plywood box which supports the antenna requires periodic checks. The 6 volt filament supply battery for the cathode follower lasts approximately 500 hours with intermittent operation. The cathode follower plate supply consists of two 45 volt "B" batteries connected in series. Frequent checks should be made on the "B" battery terminals because of corrosion growth. The plate supply voltage should not drop below 80 volts for most efficient operation. Also, the terminals at the base of the antenna proper tend to corrode. Corrosion at this point would have an effect of signal attenuation. After a severe local electrical storm the airgap type lightning arrestor mounted at the base of the antenna should be investigated for ground continuity. It is recommended that additional non-conducting paint be applied to the plywood antenna box annually to prevent moisture from entering and neutralizing the circuit.

A switch which controls the supply voltages for the cathode follower is located on the outside of the antenna box.

Sferic Amplifier

The sferic amplifier is a conventional shunt-compensated video amplifier with a linear frequency response of 1 kilocycle to 150 kilocycles and a mid-band gain of 15. It utilizes 2-6AG5's operated Class A_1. The amplifier is mounted on a small chassis separate from the trigger circuit chassis and obtains its power from the power supply located on the trigger circuit chassis. The signal input and output circuits are through coaxial cable. A volume control is incorporated in the design to limit signal strength, which must be decreased during severe local storms or distant storms of very high intensity. Under these conditions sferics are received with great rapidity and large amplitude, making it difficult to adjust the trigger circuit to precision operation.

Maintenance of the sferic amplifier consists of periodically testing the 2-6AG5's for a minimum value of transconductance (g_m) of 4,750 micromhos. Observation of waveforms presented on an oscilloscope indicates that the gain of the video amplifier should be kept within the upper one-half of minimum to maximum. If the gain is below the higher half scale the amplifier tends to introduce distortion in the sferic signal waveforms or to cause erratic gate pulses to be emitted to the oscilloscope. Since this does not extend to the camera relay, there results either overexposure of the film or a reduction of waveform detail.

Trigger Circuit

The trigger circuit is used to actuate the sweep on a type 250 DuMont oscilloscope to switch on a stroboscopic light which illuminates a time-date clock located inside a light-tight box, and to operate a rotary solenoid which drives a recording camera. It is obvious, therefore, that the trigger circuit, because of its multiple function, poses the greatest operational and maintenance problem.

Trigger Circuit - Signal Tracing

Since it is desirable to obtain records of sferics which may be of either positive or negative polarity, a transformer input push-pull amplifier and rectifier are incorporated in the trigger circuit to produce a signal voltage output of single polarity. The output of the voltage amplifier is applied to a blocking amplifier which prevents passing of a signal during the time a waveform is being photographed and the film is advancing. The output of the voltage amplifier is also applied to a conventional one-shot multivibrator which triggers the sweep of a type 250 DuMont oscilloscope.[1] The vibrator also supplies initiating pulses to a strobotron tube which illuminates a time-date clock and to relay located on the top of the trigger circuit chassis which in turn controls a relay equipped with heavy duty contacts to control the 110 volt 60 cycles per second

---

[1] A feature of the type 250 DuMont oscilloscope is that voltages of either polarity may be applied because of bi-polarized synchronization input. "Cathode Ray Oscilloscope", Type 250, Operating and Maintenance Manual, Allen B. DuMont Laboratories, Inc., 1000 Main Ave., Clifton, New Jersey. Pg. 16.

input to a rotary solenoid which drives a recording camera.

It was found necessary to insert a 1,500 ohm, 2 watt resistor in series with the coil of the multivibrator-controlled relay in order to damp the oscillations present in a pulse from the multivibrator. Also, by reference to tube characteristics after voltage measurements on the non-conducting tube of the triggering multivibrator, it was found that the normally cut off tube was conducting. Replacement of a 1 megohm grid resistor by a 2 megohm grid resistor cut off the tube by a margin of 5 volts. This was sufficient because the sferic amplifier was still able to pulse the multivibrator into operation.

Recording Equipment

The waveform of each detected sferic is amplified and placed on the screen of the type 250 DuMont oscilloscope. A photograph is simultaneously made with a modified 35 mm. motion picture camera which was developed in the Oklahoma Institute of Technology Engineering Research and Development Laboratory. For this research project the necessary camera modification consisted of converting the film driving motor, which was operated on 24 volts direct current, to a rotary solenoid which is operated by 110 volts, 60 cycles per second source obtained from the trigger circuit. A pulse which is generated by the trigger circuit multivibrator is fed to a relay located on the underside of the trigger circuit chassis. This controls the 110 volts applied to a rotary solenoid film driver. A delay inherent in the camera circuit provides adequate time for the film to advance one frame between sferics despite the fact that the same multivibrator pulse initiates both the oscilloscope sweep and the camera driver.

One of the recording equipment operational problems is that of applying the correct amount of power to the film driving rotary solenoid. There was a 5,000 ohm carbon rheostat located on the front panel of the trigger circuit chassis which controls the output voltage to the film driver. During a period of intense sferic activity, the operating time constant of the driving rotary solenoid becomes long compared to that of the multivibrator pulse. Unless the voltage applied to the rotary solenoid is of such magnitude that it may be controlled by a very short period of control relay contact, the rotary solenoid will load back on the trigger circuit. This loading-back operation is shown in Figure 1. Adjustment of voltage applied to the camera solenoid must be made for each distinct degree of intensity of a storm in order that film advancement in the camera will be one frame for each detected sferic. To increase the voltage applied to the film driving solenoid, the rheostat mounted on the front panel of the trigger circuit should be turned clockwise, and vice versa to decrease voltage.

During the loading back period described above it was found that the current drawn by the film driver, when attempting to keep pace with detected sferics, was so large as to cause arc-over at the 5,000 ohm carbon potentiometer control. This potentiometer has been replaced by a 5,000 ohm, wire wound, 25 watt rheostat which should provide adequate current control without flashover.

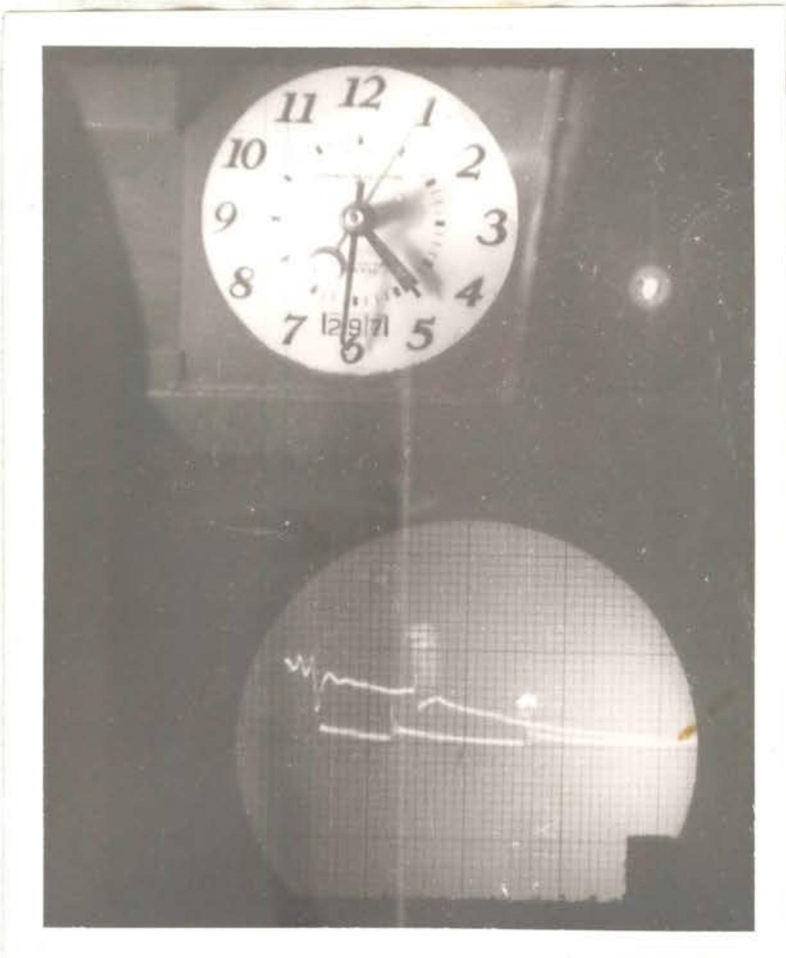

Fig. 1—Relay Loading-Back

Film Installation

A film loading diagram is located on the inside of the camera coverplate. There should be a slack loop of film between the input film driving cog wheel and the lens plate to prevent the film from being torn from the abrupt action of the driving solenoid. The film should be pulled tight between the lens plate and output cog wheel to prevent blacklash of film.

Camera Maintenance

A very small amount of light weight oil should be applied annually to all moving parts inside the camera cover plate. The rotary driving solenoid is packed in grease and should require no maintenance. Powdered resin may be applied to the film output driving belt to prevent slippage.

Oscilloscope Operation

Dial settings for proper operation of the type 250 DuMont oscilloscope appear in Table 1. One control, the synchronization gain switch, requires additional explanation however. It may be noted by observing the control panel of the type 250 DuMont oscilloscope that the synchronization gain is continuously variable in the plus to minus or minus to plus directions. The phase inverter and rectifier circuit in the input to the amplifier-trigger circuit provides a sferic polarity which is plus to minus, thereby designating utilization of the plus to minus variation of synchronization gain. Adjustment of synchronization gain is very critical. Care must be taken to adjust the gain only high enough to trigger the time-base generator of the oscilloscope with the initiating trigger pulse obtained from the trigger circuit multivibrator. If the synchronization gain is too low, the pulse from the trigger circuit is not sufficient to start the oscilloscope sweep generator and no waveform can be presented on the screen of the oscilloscope with consequent film waste. If the synchronization gain is too high, either the waveforms presented are distorted or multiple waveforms are presented which are detected with sufficient amplitude to trigger the oscilloscope sweep generator but not the film driving rotary solenoid. This results in multiple exposures of one film frame or in actual fogging of the film.

A synchronization gain value of plus or minus 10 has been found to give the most precise and accurate waveform recording. It is recommended that mechanical vernier adjustment be placed on the synchronization gain control because of its critical nature.

TABLE I

OSCILLOSCOPE ADJUSTMENTS

NAME	DIAL SETTINGS
Upper and lower deflection plates	None
Left and right deflection plates	None
Y position	Operator's convenience
X position	Operator's convenience
Intensity	Blue glow apparent on screen
Focus	Operator's convenience
External sync.	Input from trigger circuit
Sync. gain	Approximately plus to minus 10
Y selector	D.C. amplifier
Sync. selector	Internal
Sweep range	20,000 cps
X selector	Sweep
Y gain	100
Calibrator volts	Off
Sweep	Driven
X gain	40-60
Y input	Input from trigger circuit
Y attenuation	1:1
Z input	None
X attenuation	1:1
X input	None

CHAPTER IV

FINDINGS AND CONCLUSIONS

The results of operating the sferic recording equipment during the spring and summer months of 1951 have, in the writer's opinion, been conclusive. Sferic waveforms presented on the oscilloscope screen together with film records of actual storms seem to warrant the conclusion that there are distinct sferic waveforms characteristic of tornadoes. It appears beyond the capacity of the sferic recording equipment herein employed to distinguish between sferic waveforms generated in an incipient tornado and in a grounded tornado. However, present indications that a grounded tornado, or a tornado funnel that does not reach the ground, is evidenced by a radical increase of high frequency sferics. This will depend on the correlation of the sferic data with accurate visual observation of the time and location of each tornado. During the course of this study the writer operated the sferic recording equipment during a long period of tornado incipiency which culminated in a destructive windstorm in Ripley, Oklahoma, 20 miles from Stillwater. The sferic waveforms recorded during this storm were not distinguishable from those recorded during actual tornadoes.

Sferics Generated by Lightning

Despite dissenting opinions of several observers,[1] it is

---

[1] See L. W. Austin, "Direction of Atmospherics in Wireless Telegraphy", Journal of the Franklin Institute, Vol. 121 (1921), pp. 619-720; F. Schindelhauer, "Two Different Kinds of Atmospherics", Electrische Nachricten-Technik, Vol. 9 (1932), pp. 41-45; and Smith-Rose, op. cit., Vol. 3, pp. 20-25.

difficult not to accept as valid the thesis that sferics are generated by lightning discharges emanating from thunderstorms and other severe atmospheric disturbances. The writer had many opportunities to watch thunderstorms and lightning discharges in the immediate vicinity of the sferic research station. He noted visible cloud-to-ground and cloud-to-cloud lightning discharges which culminated in action of the sferic recording equipment. By noting the time and date of visible lightning discharges, it was possible to match these discharges with exact pictures of the generated sferics on the recorded film.

Frequency-Color Correlation

Significantly enough, correlation between lightning color and the frequency components in recorded sferic waveforms was observed. During a period of what may be termed a "light thundershower", the visible lightning discharges appeared yellow in color. During a thunderstorm of high intensity, the lightning discharges were distinctly violet or purple. A study of the mass spectrum will show that yellow is a long wavelength or low frequency color and that purple or violet is considerably shorter in wave length or high in frequency color. The significance of this correlation is shown by a comparison of Figures 2 and 3. Figure 2 shows a sferic waveform recorded during a light thundershower and which was initiated by a lightning discharge yellow in color. This waveform is relatively smooth. Figure 3 depicts a sferic waveform recorded during a thunderstorm of high intensity. Its associated lightning discharge appeared purple in color. High frequency modulation is apparent, and corresponds

Fig. 2—Low Intensity Thunderstorm Sferic Waveform

Fig. 3—High Intensity Thunderstorm Sferic Waveform

to much higher energy levels.

Persons who have experienced tornadoes have commented on the preponderance of blue and purple colored lightning during such storms. These observations suggest possible fruitful research for the future. A recording spectrograph or spectrometer might provide a clue to the identification of destructive windstorms or tornadoes.

Tornadoes and Destructive Windstorms in May and June, 1951

Because of the great quantities of sferics recorded during this project, it was deemed necessary to limit descriptions of storms and tornadoes to those of a relatively short period. The period of May and June, 1951, was chosen, because tornadoes are more frequent in Oklahoma during this time. Descriptions of the storms and their accompanying sferic waveforms occurring during the specified interval are presented in the following discussion.

Storm of May 30, 1951

During the two-day period prior to May 30, 1951 there had been a cold front moving toward the Oklahoma-Texas Panhandle from a northwesterly direction. The weather map provided for this research project by the Oklahoma A. and M. College Department of Meteorology indicated the existence of this moving cold front and also that the Oklahoma-Texas Panhandle was a high temperature-low pressure area. A cold front moving over a hot air mass is one of the primary conditions for tornado development. This particular weather condition culminated in a windstorm that for a period of 15 minutes exhibited velocities as high as 80 miles per hour in the Guyman, Oklahoma area. The windstorm was followed by a severe lightning and thunder storm which lasted for several hours. Time-sequential sferic waveforms are shown in Figures 4 and 5. The movement of the cold front was such that it also overran a high temperature-low pressure area near Scotts Bluff, Nebraska, with a resulting tornado. The distance (560 miles) to Scotts Bluff was too great to record sferics generated by the tornado, although some low amplitude high frequencies were in evidence.

Storm of May 31, 1951

The sferic recording equipment was put into operation after notification by the weather bureau that another critical area existed. The storm was essentially the same as that of the day before. The station at Borger, Texas recorded winds in excess of 65 miles per hour, and Woodward and Elk City, Oklahoma, reported heavy thunderstorms and damaging winds. Some of the sferic waveforms recorded during this storm are shown in Figures 6 and 7.

Storm of June 1, 1951

Weather conditions were again essentially the same as those of the two preceding days. A new cold front was moving from a northwesterly direction toward the Oklahoma Panhandle. Again the western half of Oklahoma formed the center of a high temperature-low pressure area. The resulting storm swept from Cyril, Oklahoma, past Ponca City, Oklahoma, in a northeasterly direction. The recorded wind velocity in Cyril was 75 miles per hour, which resulted in extensive damage. The sferic waveforms recorded during this storm are shown in Figures 8 and 9.

Storm of June 7, 1951

Weather maps for the two days preceding June 7, 1951 indicated a low pressure area surrounding the eastern half of Oklahoma. A slowly forming cold front was also shown in the Rocky Mountains. On June 7, 1951 a sharp break in the front line defined a large cold front on the south end and a warm front on the north end. The path of the break was toward the center of the low pressure area. At approximately 6:00 p.m. three or four tornadoes ripped into a farming area northwest and northeast of Oolagah, Oklahoma. Extensive damage was reported. The sferic waveforms for this tornado are shown in Figures 10 and 11. The waveforms do not show as many high frequency components as would normally be expected because of ground-distance attenuation. However, the energy level of the tornado is apparent from the amplitude of the sferic waveforms.

Notes recorded in the sferic research station log for this date show that sferic activity was very great and that heavy cumulo-nimbus clouds were visible to the northeast and northwest. Other information logged was that clouds moved from the south and southwest and then wheeled abruptly east. This may be explained by the squall line break from cold front to warm front. A preponderance of purple colored lightning was also noted.

Storm of June 8, 1951

The weather bureau reported that conditions were much the same as on the day before. An examination of the daily weather map showed three squall lines; one directly north of Oklahoma, one on the western edge, and one in the southeast third of the state. A low pressure area covered the greater part of the state. A tornado struck the community of Corn, Oklahoma, destroying or damaging 40 buildings. The town reported an accompanying hail storm. The sferic waveforms appear in Figures 12 and 13.

There appears to be a correlation between tornadic weather conditions and hail storms. The explanation probably lies in one of the prerequisites for a tornado, namely, that there must be a cold front moving over a hot air mass. The normal path for hot air to follow is to the upper atmosphere. When this hot air rises through the cold air, the moisture carried by the hot air is condensed and frozen. There then follows a succession of rising and falling of the hail due to the convection current of the heated air which is upward and the gravitational pull on the hail until the weight of the hail causes the gravitational force to exceed the upward force due to the heated air updraft. The hailstone will then fall to the ground.

The rising of a heated air mass through a cold mass may be sufficient to initiate the series of events which culminate in a tornado. It may induce an instability in the cold front such as to cause the cold front to attempt to move downward through the hot air. A series of updrafts and downdrafts may well cause boiling or cloud rotation. Then, in a low pressure area, the clouds may descend with a high velocity rotation and result in a grounded tornado.

Storm of June 13, 1951

The occurrence of the storm on June 13, 1951 was exceedingly difficult to correlate with conditions shown on the daily weather map. The center of a high pressure area was formed in Oklahoma. A squall line existed 300 miles to the southeast of the state. No other typical conditions for a tornado were apparent on the weather map of June 13, 1951. The weather map for June 14, 1951 did, however, show areas of violent weather conditions all over Oklahoma. A probable explanation is that Oklahoma contained a high pressure area and could therefore produce its own extreme atmospheric conditions.

Log notes recorded during the storm indicate that heavy cumulo-nimbus clouds appeared to the west-southwest. There was hard driving rain and small hail. Many clouds approached the ground, but none had characteristic funnel shapes. Large amplitude, high frequency sferic waveforms were recorded as shown in Figures 14 and 15. A peculiar cloud action is also reported in the log. The clouds first followed a path from southwest to northeast, abruptly shifted directly north, then wheeled east.

The conditions outlined above appear to describe an incipient tornado. The energy level of the generated sferics was sufficiently high to indicate a tornado. The duration and intensity of the sferics generated were respectively long and high. The frequency components of the generated sferics indicated tornadic conditions.

The storm, as mentioned previously, was centered over

Ripley, Oklahoma. It consisted of very high velocity wind and large amounts of hail. The winds and hail did extensive crop and property damage in Ripley.

Professor W. E. Hardy, head of the Oklahoma A. and M. College Meteorology station, has indicated the possibility that the Ripley winds and thunderstorm were generated locally in the high pressure area which existed. He also has pointed out that the immediate high pressure area could have been somewhat lower in pressure than a surrounding pressure area. This latter condition was not apparent on the daily weather map.

Conclusions

The sferic waveforms recorded during the course of this study are far more conclusive as concomitants of tornadoes than heretofore existing literature would indicate.

A review of pertinent research enabled the writer to compile a list of weather and atmospheric conditions typical of tornadoes, reference to which indicated when and where a tornado or destructive windstorm was likely. When these conditions appeared on daily weather maps, the sferic waveform recording equipment was put into operation to obtain visual records of sferics generated.

The premise that tornadoes and destructive windstorms possess characteristic sferic waveforms has, in the writer's opinion, been thus validated. A comparison of the sferic waveform pictures for thunderstorms and tornadoes will indicate differences in degree of intensity, duration of the sferic pulse, frequency components, and amplitude. In the majority of the tornadoes recorded during this study, it was found that the amplitudes and intensities of recorded sferics were relatively much larger and higher, respectively. The frequency components of recorded sferics were found to be relatively much higher during a tornado. These identifying characteristics of tornadoes may be explained by the energy level of tornadoes, which accounts for their notorious destructivity.

In conclusion, it does not seem presumptuous to suggest that the establishment of a series of observation stations similar to the sferic recording station at Oklahoma A. and M. College offers the most feasible means to locate and to identify tornadoes and destructive windstorms. An adequate warning system could then be instituted.

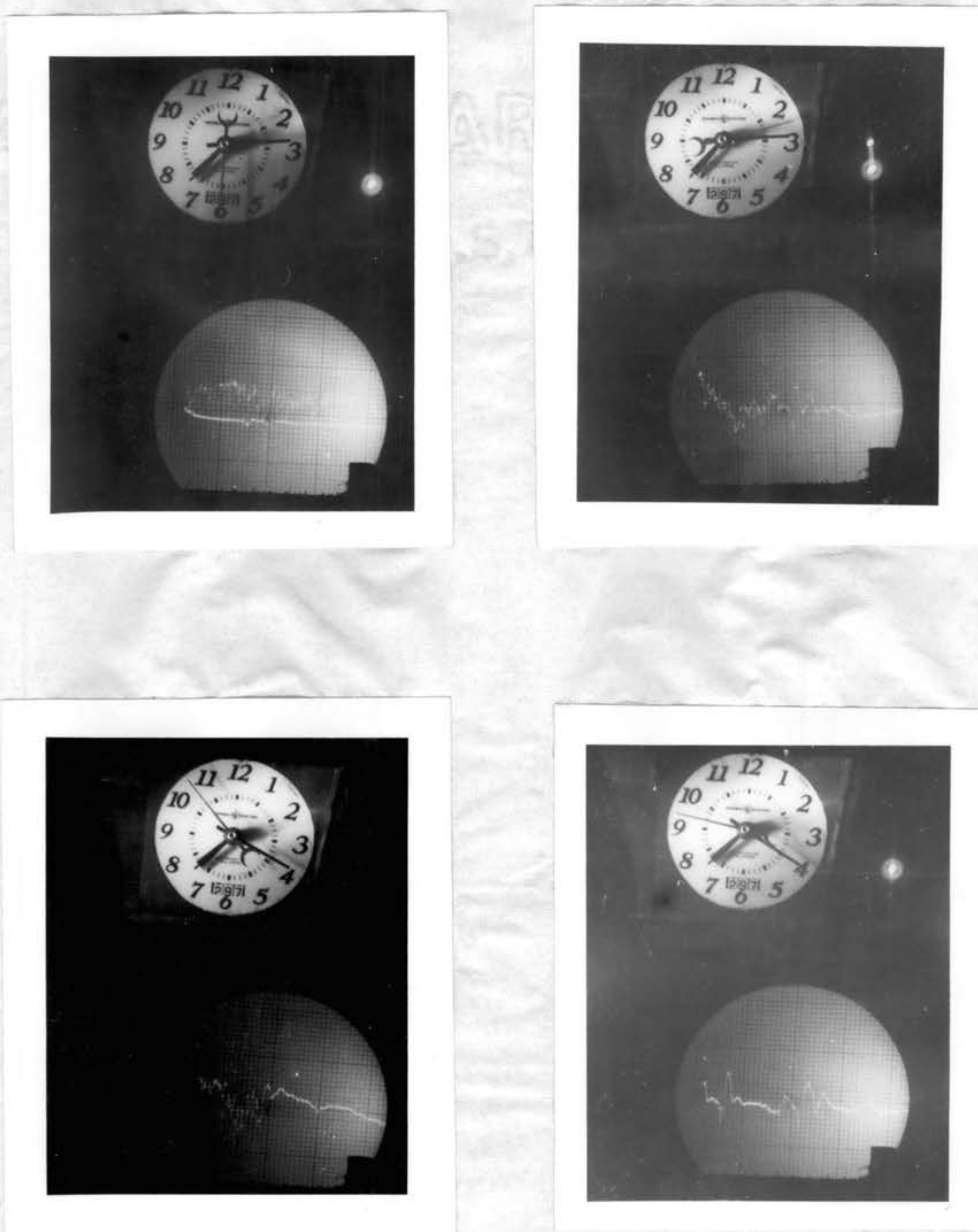

Fig. 4—Storm of May 30, 1951

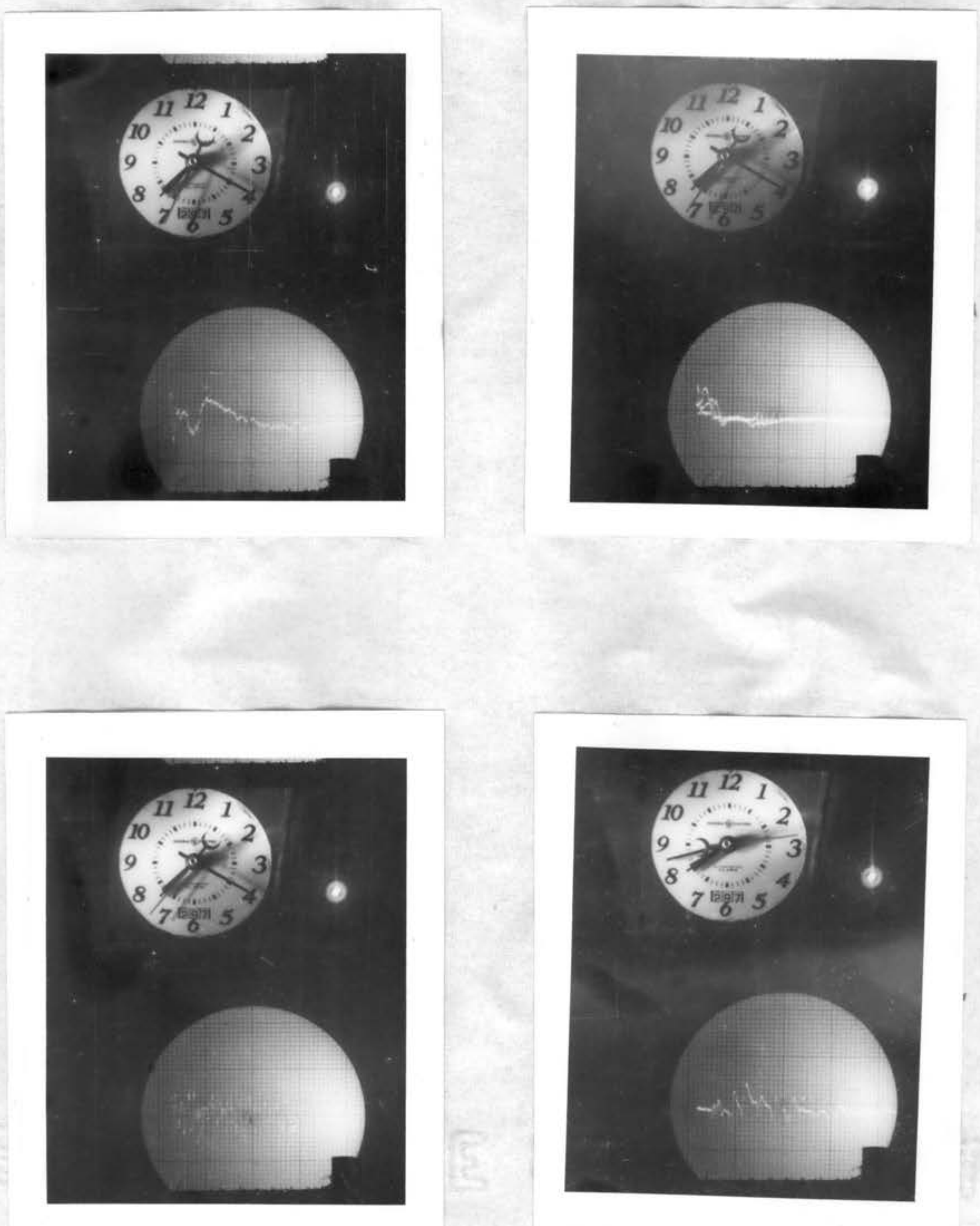

Fig. 5—Storm of May 30, 1951

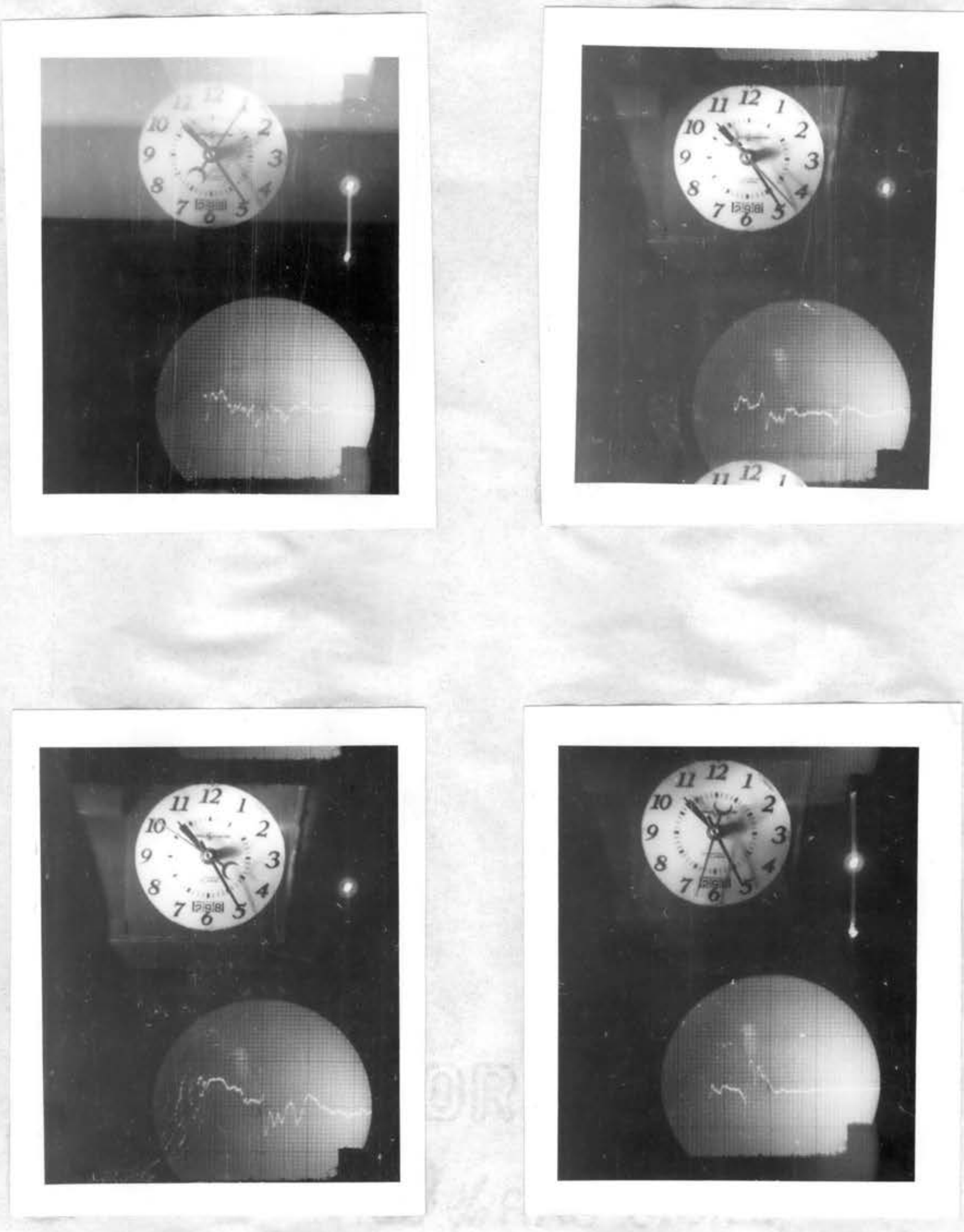

Fig. 6—Storm of May 31, 1951

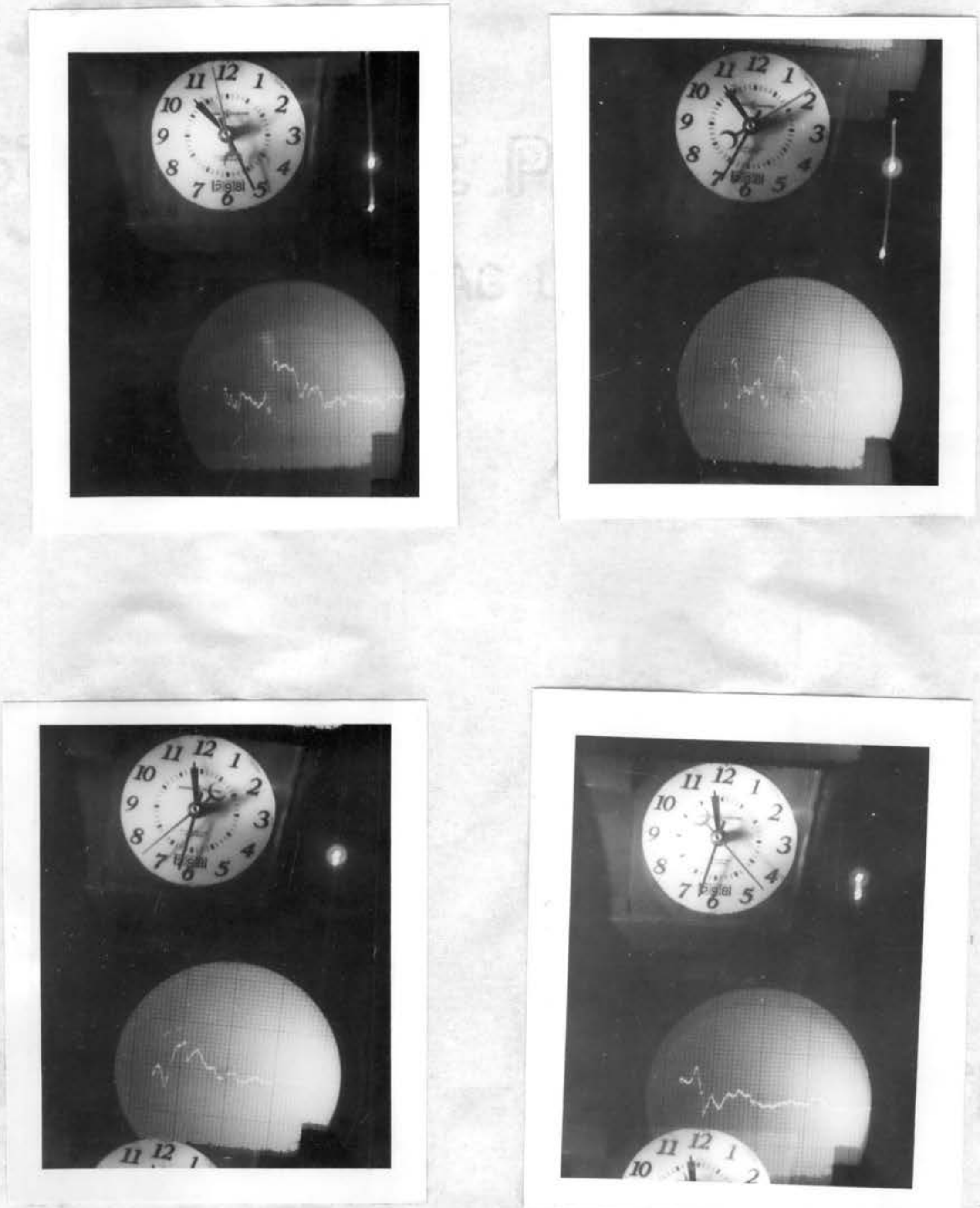

Fig. 7—Storm of May 31, 1951

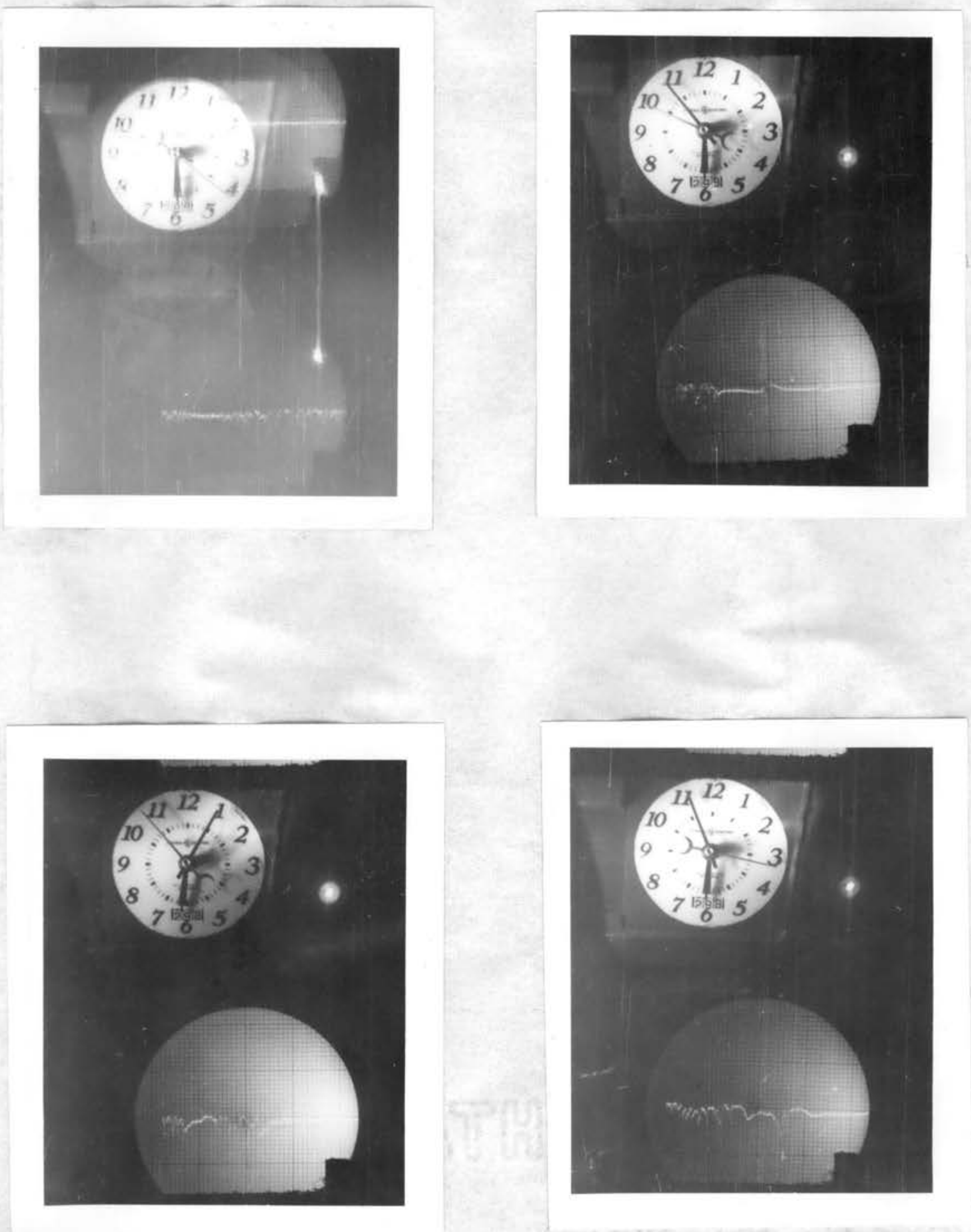

Fig. 8—Storm of June 1, 1951

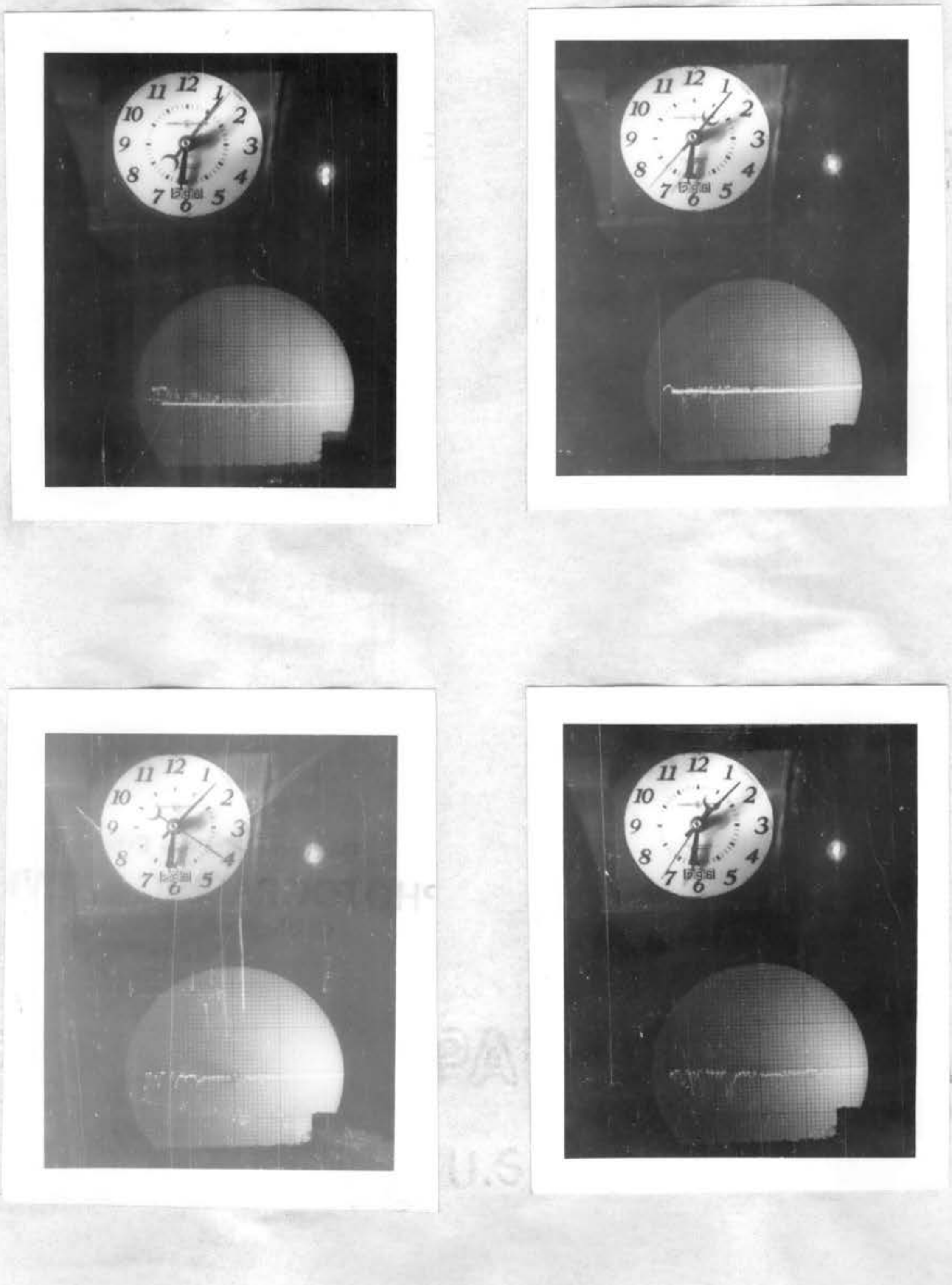

Fig. 9—Storm of June 1, 1951

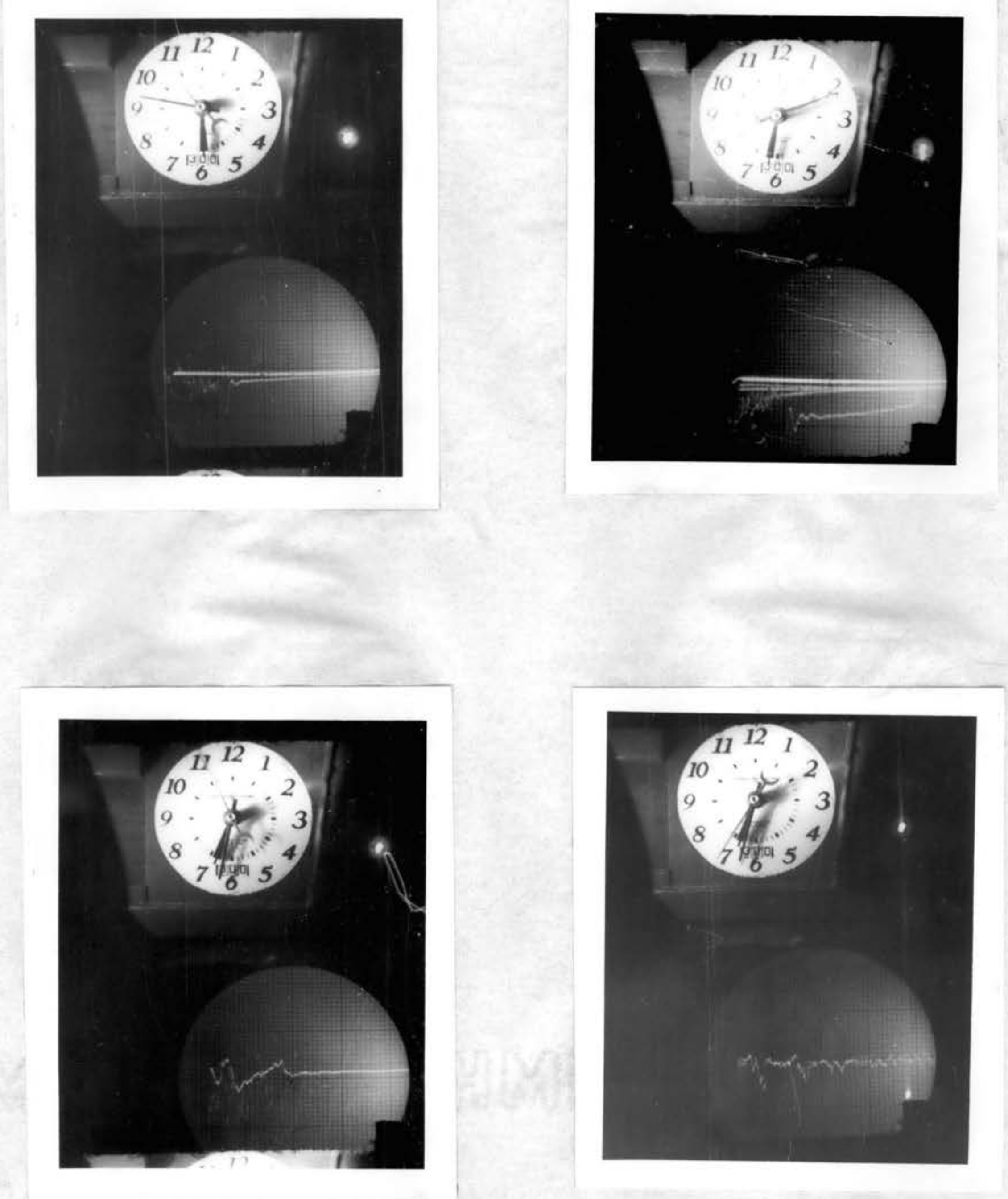

Fig. 10—Storm of June 7, 1951

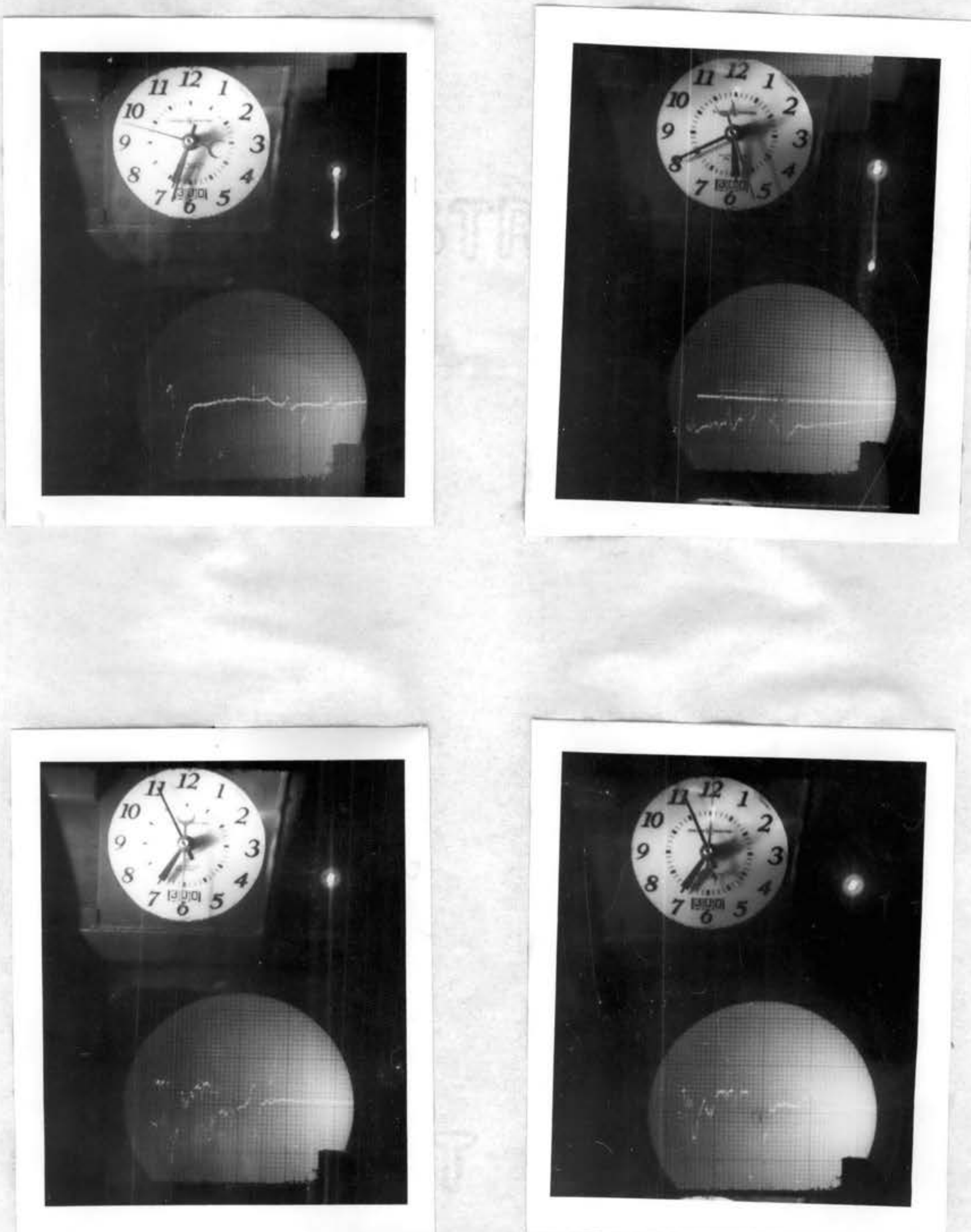

Fig. 11—Storm of June 7, 1951

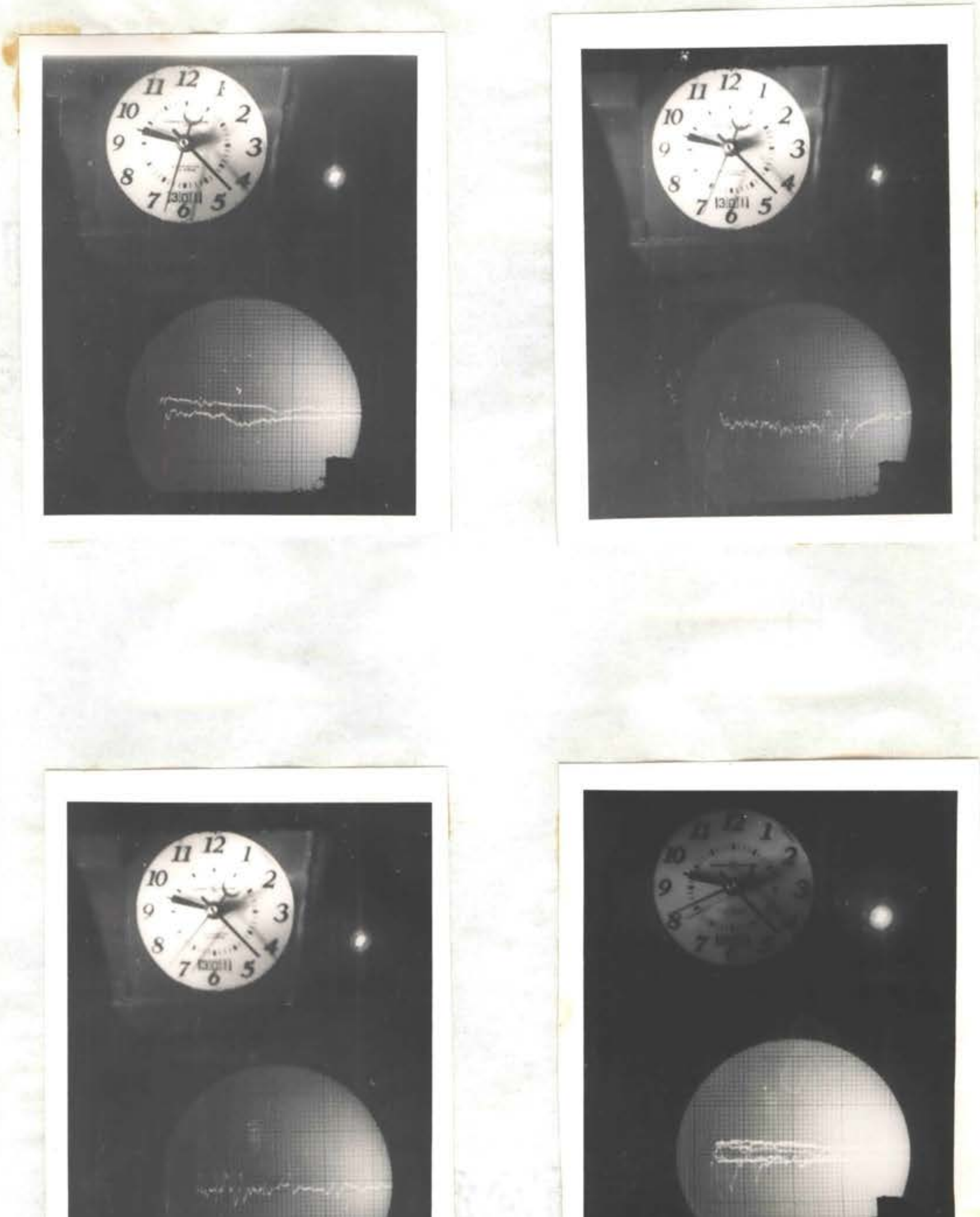

Fig. 12—Storm of June 8, 1951

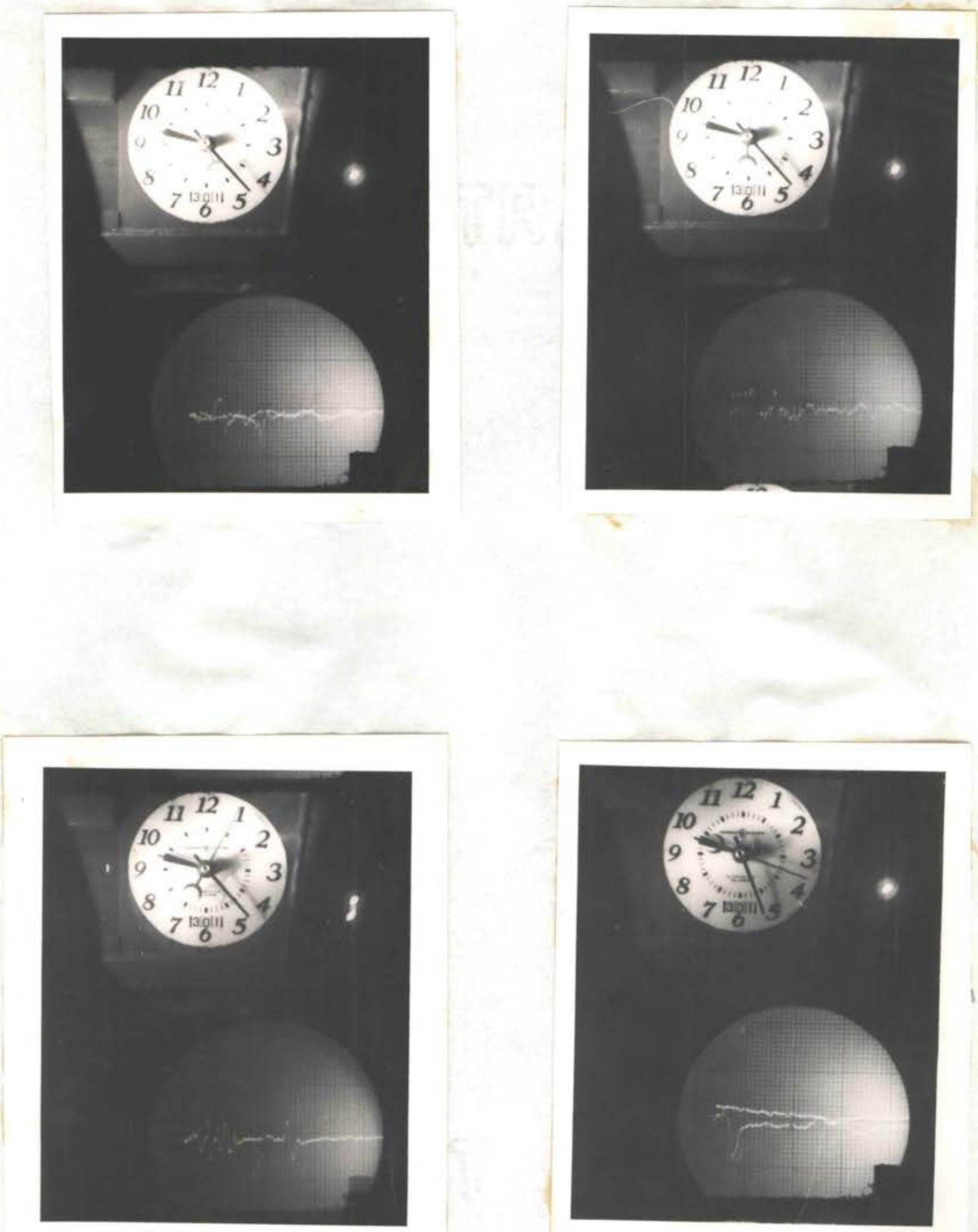

Fig. 13—Storm of June 8, 1951

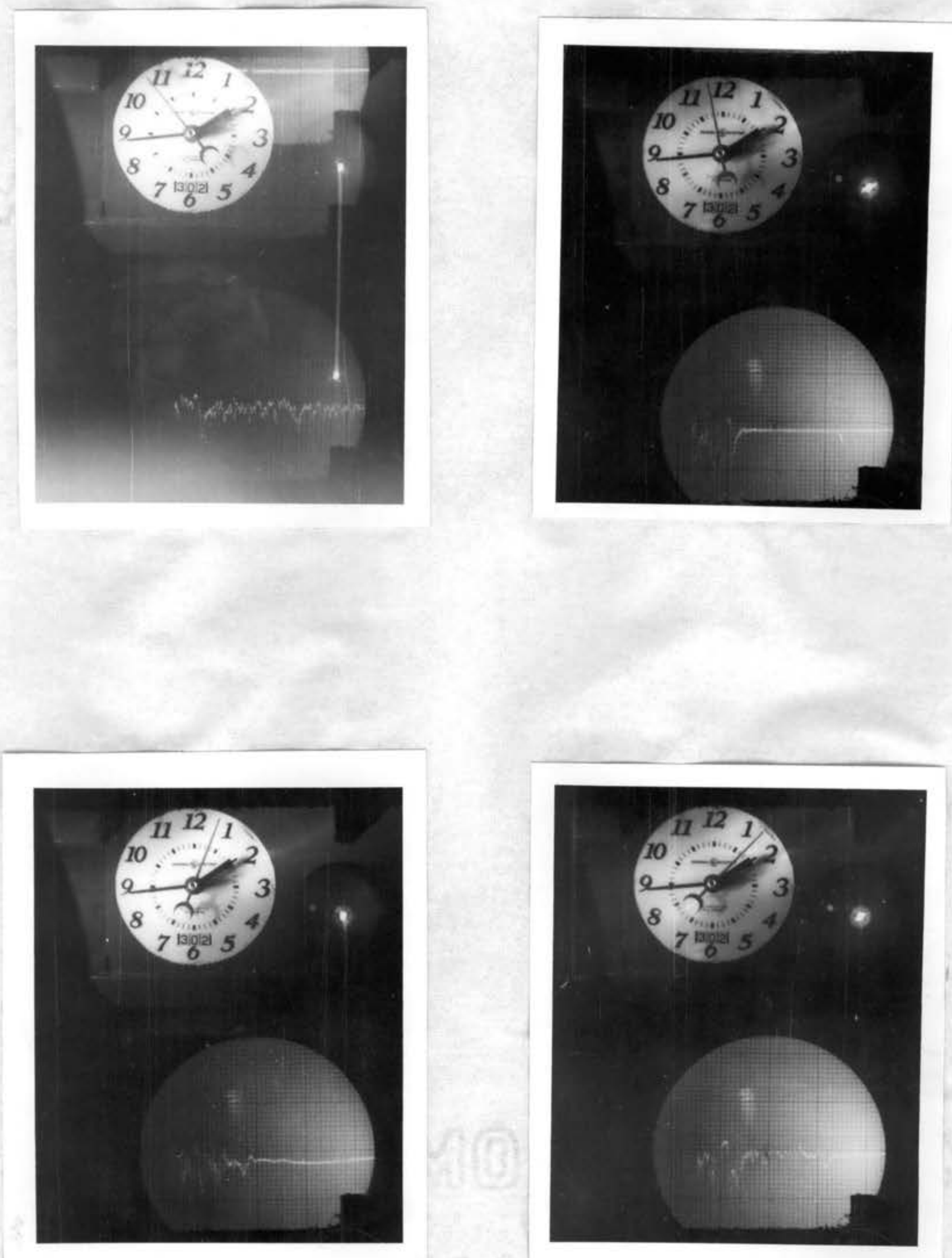

Fig. 14—Storm of June 13, 1951

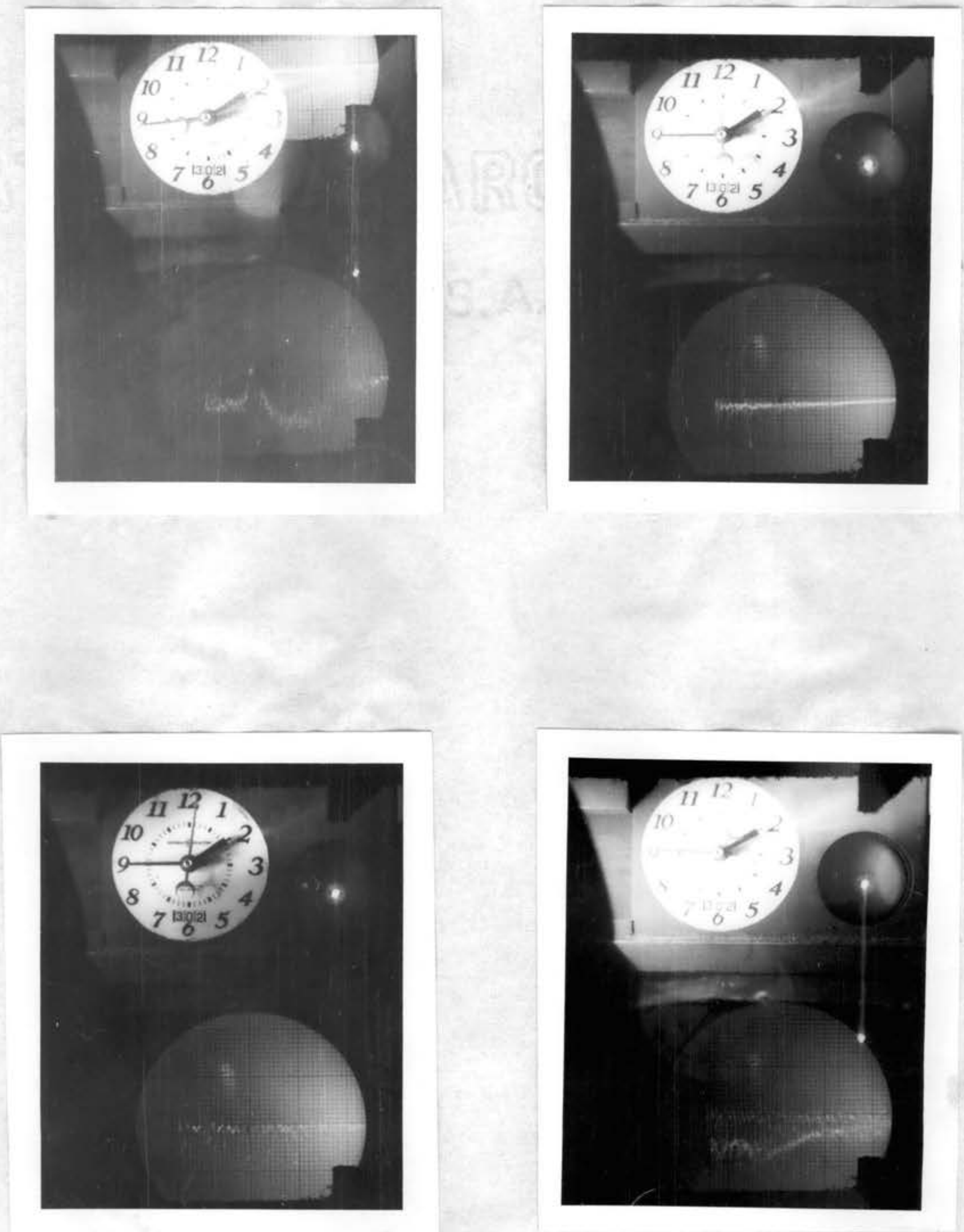

Fig. 15—Storm of June 13, 1951

Fig. 16—Sferic Amplifier and Trigger Circuit Chassis

Fig. 17—Antenna and Antenna Box

Fig. 18—Operational Site

BIBLIOGRAPHY

Austin, L. W. "The Direction of Atmospherics in Wireless Telegraphy". Journal of The Franklin Institute, Vol. 121,(1921), pp. 619-720.

________. "Radio Atmospheric Disturbances". Washington Journal of Academic Science, Vol. 16,(1926), pp. 41-46.

________. "The Relation between Atmospheric Disturbances and Wave Length in Radio Reception". Proceedings of The Institute of Radio Engineers, Vol. 9,(Feb., 1921), pp. 28-36.

"Cathode Ray Oscillograph, Type 250". Operating and Maintenance Manual, Allen B. DuMont Laboratories, Inc., 1000 Main Ave., Clifton, New Jersey, p. 16.

Fawbush, E. J., Miller, R. C., and Starrett, L. G. "An Empirical Method of Forecasting Tornado Development". Bulletin of The American Meteorology Society,(Jan., 1951), pp. 1-9.

Hess, Phillip N. "Installation and Operation of Electronic Sferic Detection Equipment". Unpublished Master's Thesis. Stillwater, Oklahoma: Oklahoma A. and M. College,(1950).

Hucke, H. M. "Precipitation Static Interference on Aircraft and at Ground Stations". Proceedings of The Institute of Radio Engineers, Vol. 27,(May, 1939), pp. 301-309.

Jeske, Harold O. "Electronic Apparatus for The Study of Sferic Waveforms". Unpublished Master's thesis. Stillwater, Oklahoma: Oklahoma A. and M. College,(1950).

Potter, R. K. "An Estimate of Frequency Distribution of Atmospheric Noise". Proceedings of The Institute of Radio Engineers, Vol. 20,(Sept., 1932), pp. 1512-1518.

Sashoff, S. P. and Weil, J. "Static Emanating from Six Tropical Storms and its Use in Locating the Position of the Disturbance". Proceedings of The Institute of Radio Engineers, Vol. 27,(Nov., 1939), p. 698.

Schafer, J. P. and Goodall, W. M. "Peak Field Strength of Atmospherics Due to Local Thunderstorms at 150 Megacycles". Proceedings of The Institute of Radio Engineers, Vol. 27, (March, 1939), pp. 202-204.

Schonland, B. F. J., Malan, D. J., and Collens, H. "Progressive Lightning II". Proceedings of The Royal Society, Vol. 153, (1935), pp. 595-625.

Smith-Rose, R. L. "Atmospherics". _World Power_, Vol. 3, (1925), pp. 20-25.

Thomason, Thomas H. "The Development of A Sferic Direction Finder". Unpublished Master's thesis. Stillwater, Oklahoma: Oklahoma A. and M. College, 1949.

Schindelhaver, F. "Two Types of Atmospherics". _Elektrische Nachrieten-Technik_, (1932)

THESIS TITLE: Sferic Waveform Identification of Destructive Windstorms and Tornadoes

NAME OF AUTHOR: James C. Hill

THESIS ADVISER: Herbert L. Jones

The content and form have been checked and approved by the author and thesis adviser. "Instructions for Typing and Arranging the Thesis" are available in the Graduate School office. Changes or corrections in the thesis are not made by the Graduate School office or by any committee. The copies are sent to the bindery just as they are approved by the author and faculty adviser.

NAME OF TYPIST: Anna Frances White